



LRFD

Section 3.80

New: January 2005

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3.80.1 General

ACCURACY REQUIRED

All capacities shall be taken to the nearest 1 (one) Ton, loads shown on plans.

MAXIMUM SPECIFIED PILE LENGTHS

Steel.....No Limit

Cast-in-Place.....No Limit

STEEL PILE

All steel in steel piling shall be A36 unless Seismic Design requires A572 (50 ksi) steel for bending stresses.

TEST PILE

Length shall be pile length + 10'.

When test piles are specified to be driven-in-place they shall not be included in the number of piles indicated in the "PILE DATA" Table.

LOAD TEST PILE

When Load Test Pile are specified, the bearing value shall be determined by an actual load test in accordance with Sec 702.

For preboring for piles see Sec 702

3.80.2 STEEL PILE

**STEEL PILE
SIZE**

SECTION	AREA
HP 10 x 42	12.35 sq. in.
HP 12 x 53	15.58 sq. in.
HP 14 x 73	21.46 sq. in.

The HP 10 x 42 section should generally be used unless a heavier section produces a more economical design. The same size pile must be used for all footings on the same bent. Pile size may vary from bent to bent.

Pile Tips

Pile tip reinforcement shall be used if specified on the Design Layout.

HAMMER ENERGY

In calculating the required hammer energy, check the charts indicated below and enter the larger value in the "PILE DATA" table on the Design Plans.

STEEL BEARING CHART (Pile Length)

(Hammer energy based on pile length – See page 4.2-1)

STEEL BEARING CHART (Design Bearing)

(Hammer energy based on "Design Bearing" – See page 4.2-2)

If the required batter differs from that indicated, see the Missouri Standard Specifications.

"Hammer Energy Required" shall not be given on Plans above a maximum value of 24,000 ft-lbs.

Whenever the piling situation results in a value over a preferable maximum of 22,000 ft-lbs, a redesign shall be made for greater number of piles so as to hold the value to around 22,000 ft-lbs. A value of 24,000 ft-lbs will be permitted for only very special situations where numbers of piles are limited by construction clearances or other circumstances.

3.80.3 Design Procedure

DESIGN PROCEDURE OUTLINE

1. Total Factored Loading from the Substructure Unit
2. Resistance Factor for Geotechnical Strength (ϕ_G).
3. Resistance Factor For Strength(ϕ_S).
4. Downdrag and Losses to Geotechnical Strength.(If applicable)
5. Preliminary Nominal Design Capacity.
6. Preliminary Factored Design Capacity.
7. Layout the Pile Group.
8. Nominal Design Capacity & Nominal Required Bearing.
9. Nominal Pile Resistance.
10. Estimate Pile Length and Check Pile Capacity.
11. Show proper Pile Data on Plan Sheets.

Draft

1. Find Total Factored Load from Substructure Unit

Calculate loading for Strength and Extreme Event Limit States. The pile resistance as set forth will satisfy the Service Limit State. Thus, calculating service loading and axial settlement of the pile is not necessary.

2. Resistance Factor for Geotechnical Strength (ϕ_G)

For displacement piles, a constant resistance factor 0.45 shall be used for side and tip resistance. This factor was discussed in NHI Course No. 13068, FHWA HI-98-032. For non-displacement piles, the resistance factor of 0.45 was divided by 1.5 to compensate for the lack of reliability in determining driven bearing. A modifier of 0.8 has been applied as required by LRFD when the ENR formula is used to verify bearing during construction.

Displacement Piles

Metal Shells $\phi_G = 0.45$

Non-Displacement Piles

H-Piles $\phi_G = \frac{0.45}{1.5} \times 0.8 = 0.24$

3. Resistance Factor for Strength (ϕ_S)

Metal Shells $\phi_S = 0.54$

H-Piles $\phi_S = 0.45$

4. Downdrag & Losses to Geotechnical Strength (kips)

Downdrag, liquefaction and scour all reduce the available skin friction capacity of piles. Downdrag (DD) is unique because it not only causes a loss of capacity, but also applies a downward force to the piles. This is usually attributed to embankment settlement. However, downdrag can also be caused by a non-liquefied layer overlying a liquefied layer.

$$\text{DD, Liq. \& Scour} = q_s A_{sa} \quad (\text{for the zone/length of pile affected})$$

5. Preliminary Nominal Design Capacity (PNDC) of an individual pile (kips)

The following is a complete listing of preliminary nominal design capacities for all allowed pile types.

The PNDC were calculated with the assumption that the piles are continually braced. This includes the portion of piling that is below ground or confined by solid wall encasement. For portions of piling that are not continually braced, the PNDC must be calculated taking the unbraced length into account.

STEEL PILES

$$\text{PNDC} = 0.66^{\lambda} F_y A_s \quad (\text{Eq. 6.9.1-1, LRFD})$$

Since we are assuming the piles are adequately braced, then $\lambda = 0$. The yield strength of the steel (F_y) shall be limited to the yield strength of the pile.

PRECAST CONCRETE PILES

$$\text{PNDC} = 0.85 (0.85 f'_c (A_g - A_{st}) + f_y A_{st}) \quad (\text{Eq. 5.7.4.4-2, LRFD})$$

6. Preliminary Factored Design Capacity (PFDC) of an Individual Pile (kips)

For End Bearing Piles:

$$\begin{aligned}\text{PFDC} &= \text{Factored Structural Strength} - \text{Factored DD Load} \\ &= \phi_s (\text{PNDC}) - \gamma_p (\text{DD})\end{aligned}$$

DD = nominal downdrag (kips)

ϕ_s = resistance factor for pile strength (dimensionless)

γ_p = load factor for permanent loads (dimensionless)

Note: For end bearing piles the geotech losses are not included. An end bearing pile is driven through soil to rock where it develops its bearing. The resistance of the soil above the rock is ignored when determining the driven bearing of the pile. Therefore, it does not need to be removed from the design capacity of the pile.

For Friction Piles:

$$\begin{aligned}\text{PFDC} &= \text{Factored Structural Strength} - \text{Factored Geotech Losses} - \text{Factored DD Load} \\ &= \phi_s (\text{PNDC}) - \phi_G (\text{DD} + \text{Liq.} + \text{Scour}) - \gamma_p (\text{DD}) \\ \phi_G &= \text{resistance factor for geotechnical strength (dimensionless)}\end{aligned}$$

Note: Downdrag is included in the factored geotech losses. This is because the pile must be driven through the soil layer which has the potential for downdrag. The resistance of this layer must be accounted for during, and the load applied must be accounted for during the downdrag event. Both, the resistance during driving and applied load, have same nominal magnitude. Therefore, to simplify the design process, we used the same variable to account for both conditions.

Preliminary Factored Design Capacities assuming no corrosion loss, downdrag, liquefaction or scour.

Type	PNDC (kips)	ϕ_s	PFDC (kips)
HP 10 x 42	446	0.45	201
HP 12 x 53	558	0.45	251
HP 14 x 73	770	0.45	347

7. Pile Group Layout

$$\text{Preliminary Number of Piles Required} = \frac{\text{Total Factored Vertical Load}}{\text{PFDC}}$$

Layout a pile group that will satisfy the preliminary number of piles required. Calculate the maximum and minimum factored load applied to the outside corner piles assuming the pile cap/footing is perfectly rigid. The general equation is as follows:

$$\text{Max. Load} = \frac{P}{\text{Total \# of Piles}} + \frac{M_x}{I_x}x + \frac{M_y}{I_y}y$$

$$\text{Min. Load} = \frac{P}{\text{Total \# of Piles}} - \frac{M_x}{I_x}x - \frac{M_y}{I_y}y$$

The maximum factored load per pile must be less than or equal to PFDC for the pile type and size chosen. If not, the pile size must be increased or additional piles must be added to the pile group. Reanalyze until the pile type, size and layout are satisfactory.

The minimum factored load per pile should preferably be greater than zero. If this cannot be practically satisfied, the factored pullout resistance of the pile shall be calculated.

8. Nominal Design Capacity & Nominal Required Bearing (kips)

The nominal design capacity and nominal required bearing must be calculated and shown on the final plans. The nominal design capacity will be used to verify the pile group layout and loading. The nominal required bearing will be used in construction to limit the minimum required driven bearing.

Factored Design Capacity (FDC) = Maximum Factored Load per Pile

$$\text{Nominal Design Capacity (NDC)} = \frac{\text{Factored Design Capacity}}{\phi_s}$$

The Factored and Nominal Required Bearings must be increased by the same geotech, losses and downdrag loads that were removed in step 6.

Friction Piles:

$$\text{Factored Required Bearing} = \text{FDC} + \phi_G (\text{DD} + \text{Liq.} + \text{Scour}) + \gamma_p (\text{DD})$$

End Bearing Piles:

$$\text{Factored Required Bearing} = \text{FDC} + \gamma_p (\text{DD})$$

$$\text{Nominal Required Bearing} = \frac{\text{Factored Required Bearing}}{\phi_G}$$

9. Nominal Pile Resistance (Q_n)

General

$$\text{Displacement Piles} \quad Q_n = q_p A_p + q_s A_{sa}$$

$$\text{Friction H-Piles} \quad Q_n = q_s A_{sa}$$

$$\text{End Bearing H-Piles} \quad Q_n = q_p A_p$$

Nominal Unit Tip Resistance of Pile (q_p)

Granular

$$q_p = \frac{0.8 N_{corr} D_b}{D} \leq q_t \quad [\text{Eq. 10.7.3.4.2a-1, LRFD}]$$

for which:

$$N_{corr} = \left[0.77 \log_{10} \left(\frac{40}{\sigma_v'} \right) \right] N \quad \& \quad q_t = 8 N_{corr} \text{ (sands)}$$

$$= 6 N_{corr} \text{ (nonplastic silt)}$$

Cohesive

$$q_p = \left(\frac{2ksi}{1tsf} \right) \bullet 9 \bullet S_u = \left(\frac{2ksi}{1tsf} \right) \bullet 9 \bullet \left(\frac{1}{2} Q_u \right) = \left(\frac{ksf}{tsf} \right) \bullet 9 Q_u$$

Note: the equation above is the same as equation 10.7.3.3.3-1, in LRFD except that the units for q_p have been changed from tsf to ksf and $\frac{1}{2} Q_u$ has been substituted for S_u . Q_u has units of tsf.

This section is to be used for H-Piles driven to rock. Neglect side resistance.

Nominal Unit Side Resistance of Pile (q_s)

Except for H-Piles driven into rock, the nominal unit side resistance should be calculated for all layers of soil that the pile must pass through, including those that are liquefiable, scourable, or those that may cause downdrag.

Granular Curved/Equations were developed for displacement piles. If nondisplacement piles are used, the box perimeter of the H-Pile in granular layers should be reduced by 25% (i.e. multiply P_s by 0.75).

Curve 1 (Hard Till)

$$q_s = 0 \quad (N < 30)$$

$$q_s = 0.00136N^2 - 0.00888N + 1.13 \quad (30 \leq N)$$

Curve 2 (Very Fine Silty Sand)

$$q_s = 0.1N \quad (N < 30)$$

$$q_s = 42.58 e^{\left[\frac{(N-175.05)^2}{-7944} \right]} \quad (30 \leq N < 74)$$

$$q_s = 0.297N - 10.2 \quad (74 \leq N)$$

Curve 3 (Fine Sand)

$$q_s = 0.11N \quad (N < 30)$$

$$q_s = 0.3256N + \frac{182}{N} - 12.51 \quad (30 \leq N < 66)$$

$$q_s = 0.329N - 9.91 \quad (66 \leq N)$$

Curve 4 (Medium Sand)

$$q_s = 0.117N \quad (N < 26)$$

$$q_s = 0.00404 N^2 - 0.0697N + 2.13 \quad (26 \leq N < 55)$$

$$q_s = 0.356N - 9.1 \quad (55 \leq N)$$

Curve 5 (Clean Medium to Coarse Sand)

$$q_s = 0.128N \quad (N < 24)$$

$$q_s = 0.00468 N^2 - 0.0693N + 2.05 \quad (24 \leq N < 50)$$

$$q_s = 0.394N - 9.42 \quad (50 \leq N)$$

Curve 6 (Sandy Gravel)

$$q_s = 0.15N \quad (N < 20)$$

$$q_s = 0.00861 N^2 - 0.217N + 3.91 \quad (20 \leq N < 40)$$

$$q_s = 0.6N - 15.0 \quad (40 \leq N)$$

Cohesive Curves/Equations can be used for both displacement and nondisplacement piles with no reduction in the box perimeter assumed for H-Piles. Note that Q_u has units of tsf and q_s has units of ksf. If $Q_u > 3$ tsf and $N > 30$, then use Curve 1 (Hard Till) from Section 9.3.1 to determine resistance.

$$q_s = \frac{-1}{2500} Q_u^3 - 0.177 Q_u^2 + 1.09 Q_u \quad (Q_u \leq 1.5 \text{ tsf})$$

$$q_s = 0.0495 Q_u^3 - 0.347 Q_u^2 + 1.278 Q_u - 0.068 \quad (1.5 \text{ tsf } Q_u < 2 \text{ tsf})$$

$$q_s = 0.470 Q_u + 0.555 \quad (4.5 \text{ tsf } \leq Q_u)$$

10. Estimate Pile Length and Check Pile Capacity

Estimated Pile Length

Friction Piles:

$$\begin{aligned}
 &= \frac{\text{Factored Required Bearings} - \text{Factored Tip Resistance}}{\text{Factored Side Resistance per Foot}} \\
 &= \frac{\phi_G (\text{Nom. Req. Brg.}) - \phi_G (q_p A_p)}{\phi_G (q_s P_s)} \\
 &= \frac{\text{Nom. Req. Brg.}) - q_p A_p}{q_s P_s}
 \end{aligned}$$

Note: The total pile length estimate shall include any pile length above the elevation at which skin friction is being developed.

End Bearing Piles

The estimated pile length is the distance along the pile from the cut-off elevation to the estimated tip elevation considering any penetration into rock. The estimated tip elevation shall not be shown on plans.

Check Pile Capacity (Axial Loads Only)

Friction Piles

$$\text{Max. Fac. Load per Pile} \leq \phi_G Q_n - \phi_g (\text{DD} + \text{Liq} + \text{Scour}) - \gamma_p (\text{DD})$$

End Bearing Piles

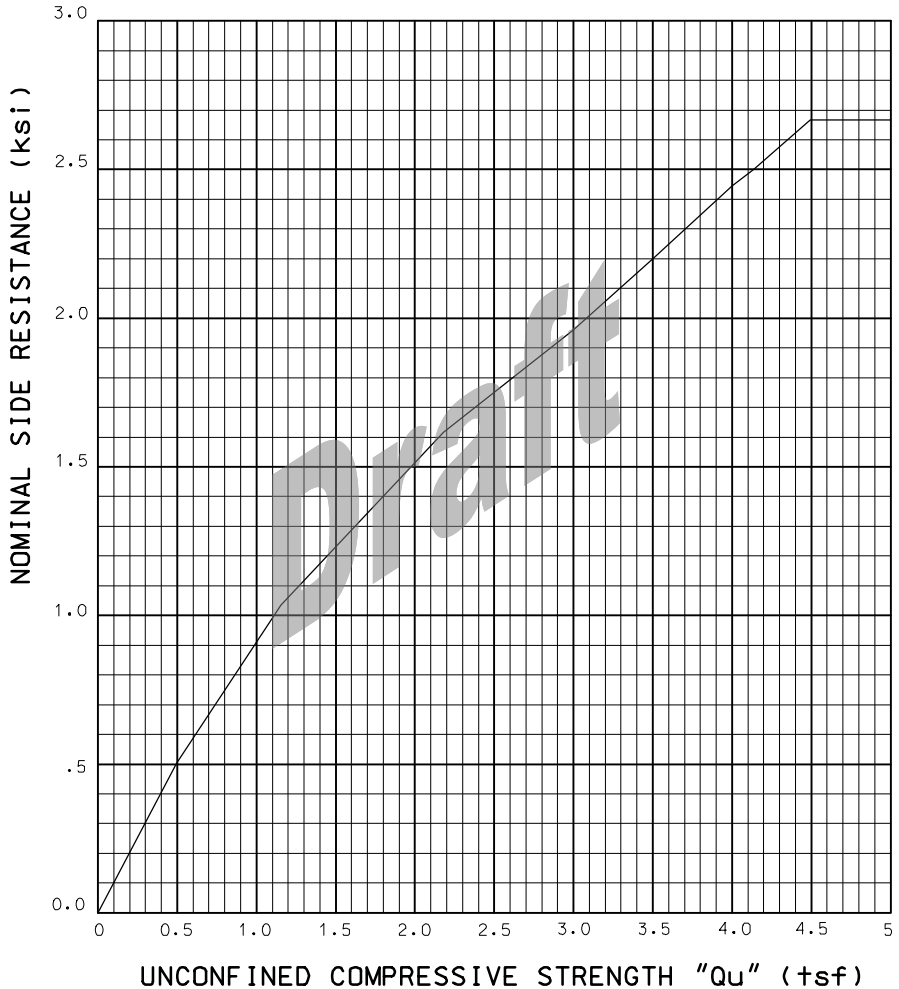
$$\text{Max. Fac. Load per Pile} \leq \phi_G Q_n - \gamma_p (\text{DD})$$

Note: The equations above are the same as Eq. 1.3.2.1-1 LRFD assuming that the load modifier (η_i) is equal to 1.0.

Check Pile Capacity (Combined Axial and Bending)

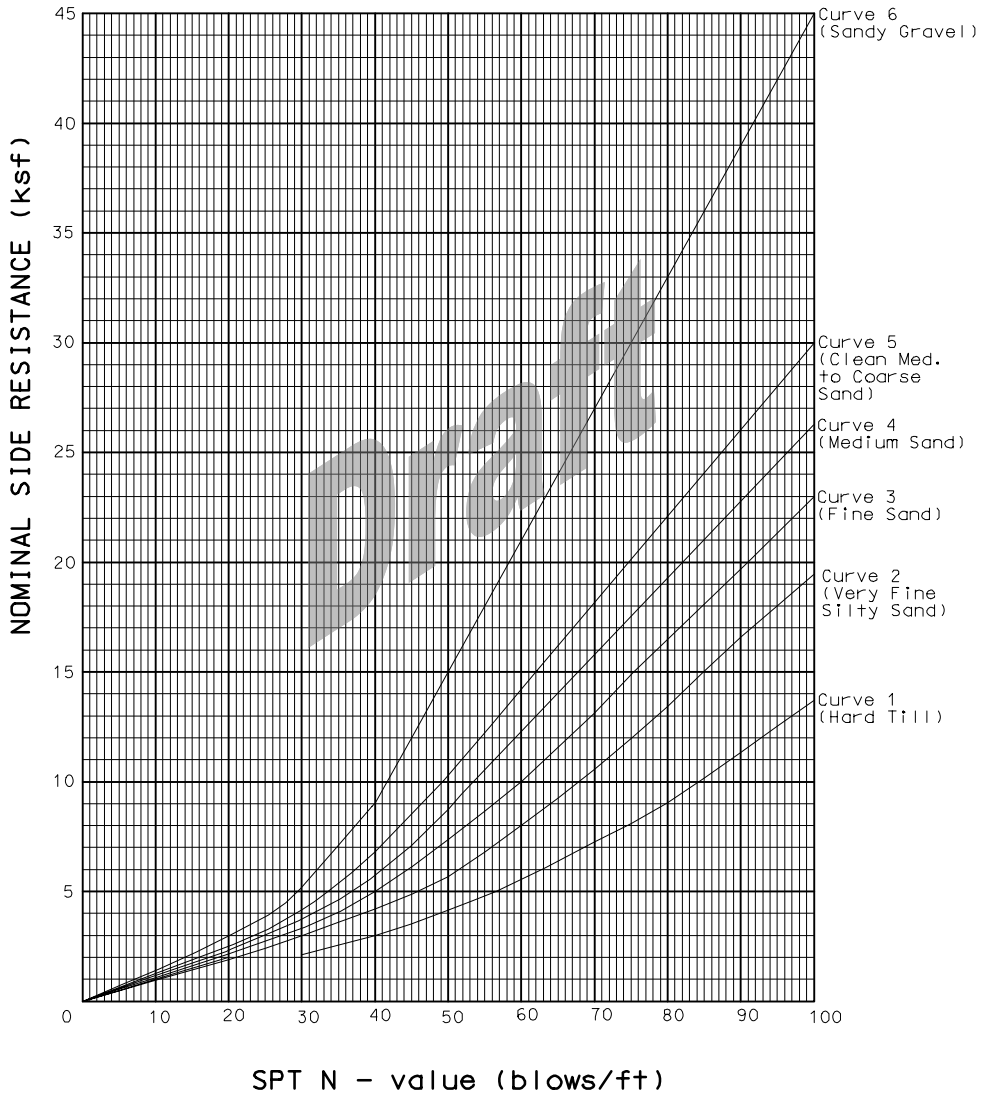
Structural design checks which include lateral loading and bending shall be accomplished using the resistance factors in Sec 6.5.4 AASHTO LRFD .

Nominal Side Resistance of Driven Piles
In Cohesive Soil Layers



Note: (If $Q_u > 3tsf$ & $N > 30$, use Curve 1 for Granular Soil to determine resistance.)

Nominal Side Resistance of Driven Displacement Piles
In Granular Soil Layers



DESIGN

Driven Pile

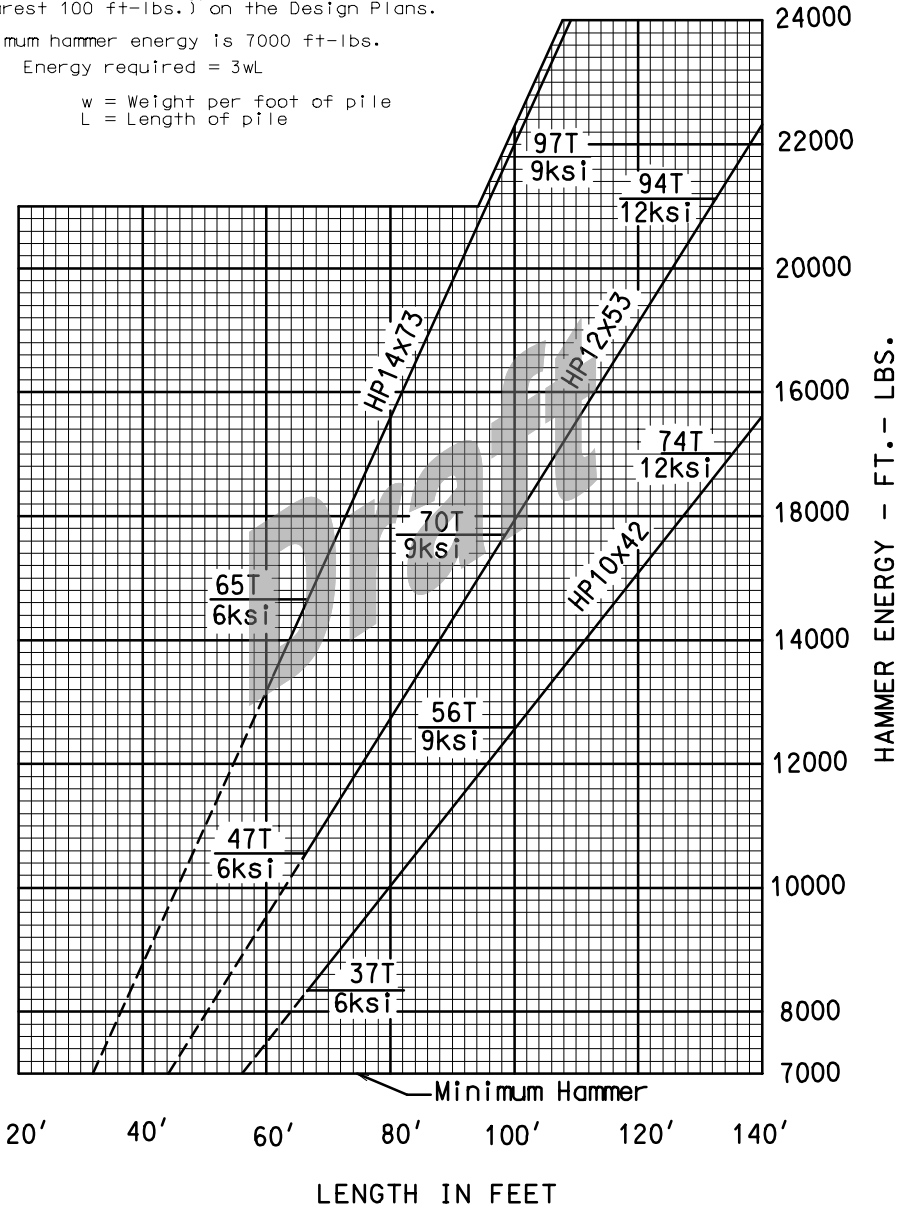
Steel Bearing Pile

Indicate hammer energy in "PILE DATA" table (nearest 100 ft-lbs.) on the Design Plans.

Minimum hammer energy is 7000 ft-lbs.

Energy required = $3wL$

w = Weight per foot of pile
 L = Length of pile



DESIGN

Steel Bearing Pile

Indicate hammer energy in "PILE DATA" table (nearest 100 ft-lbs.) on the Design Plans.

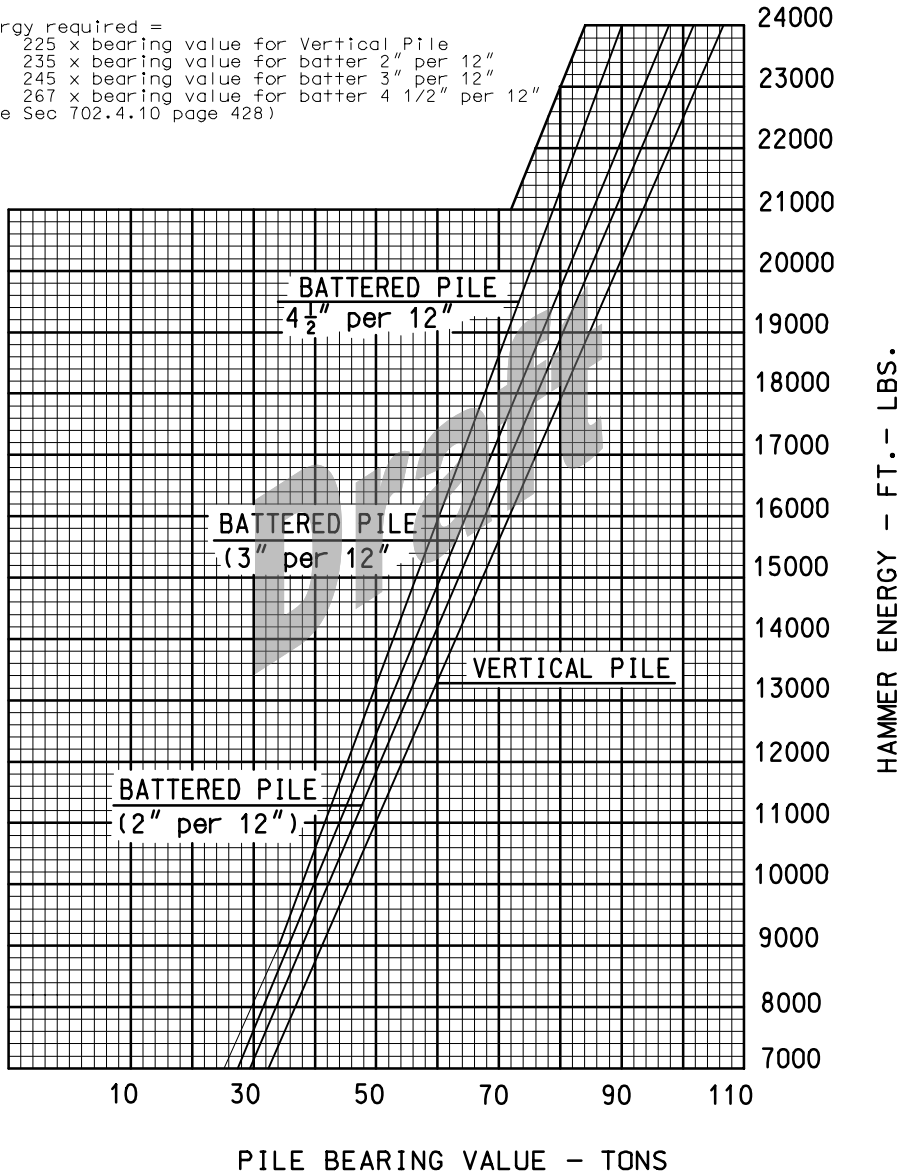
Minimum hammer energy is 7000 ft-lbs.

Energy required =

- 225 x bearing value for Vertical Pile
- 235 x bearing value for batter 2" per 12"
- 245 x bearing value for batter 3" per 12"
- 267 x bearing value for batter 4 1/2" per 12"

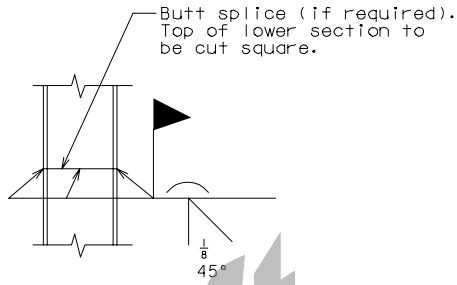
(See Sec 702.4.10 page 428)

Driven PILE



3.80.5 DETAILS

5.1 STRUCTURAL STEEL PILE SPLICE DETAIL



STEEL PILE SPLICE

Draft